NRL Memorandum Report 606

APPLICATION OF TACITRON RCA TYPE 6441 TO PULSE CIRCUITRY

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RADAR DIVISION

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ILLUSTRATIONS

FOR

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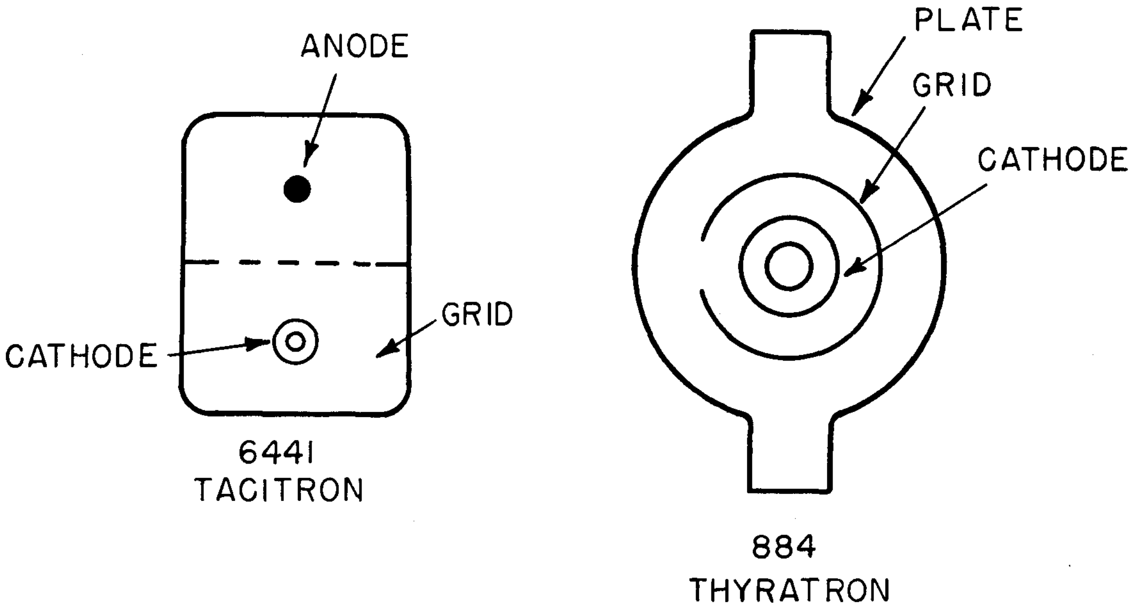


Figure 1 - Element Arrangement of a Tacitron and a Thyratron

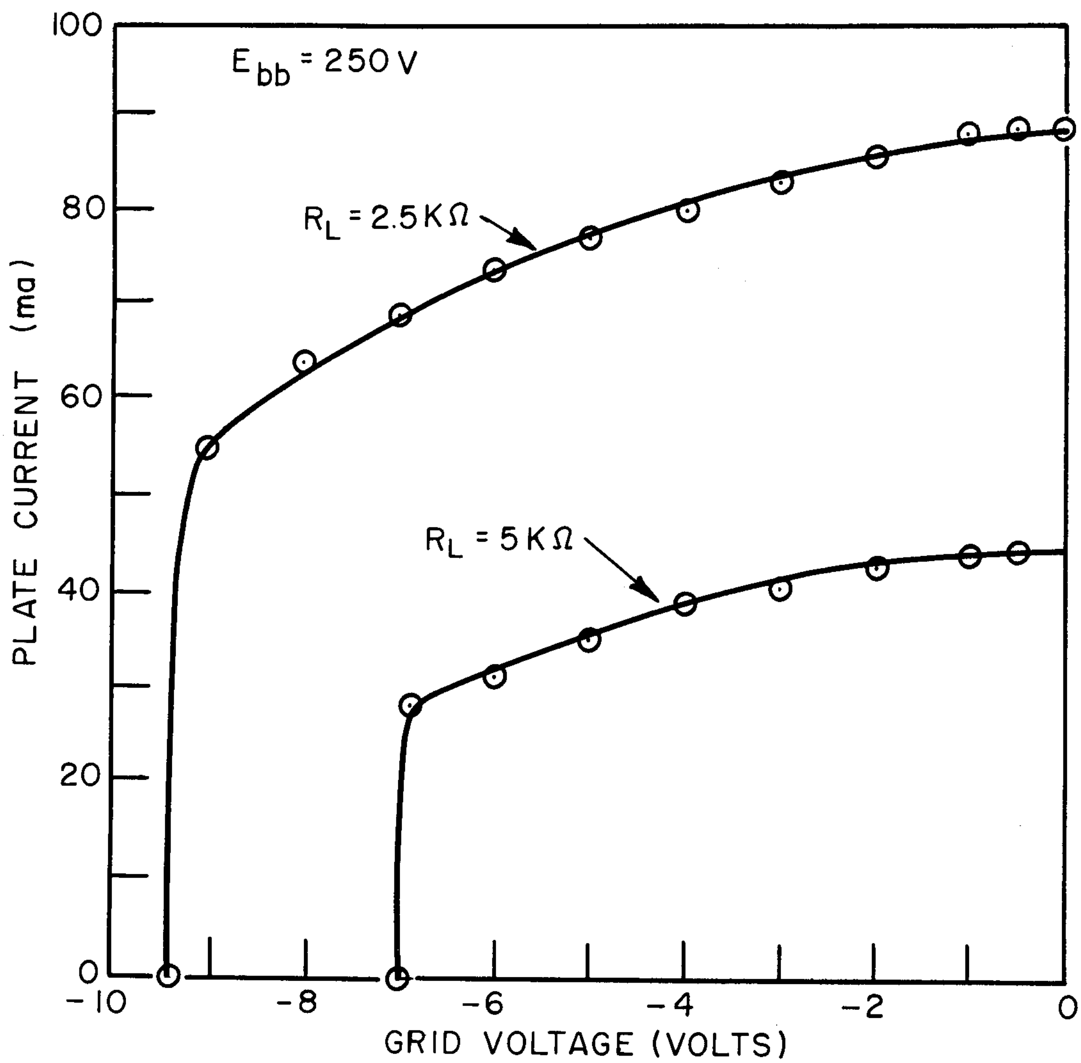


Figure 2 - Dynamic Characteristic of Tacitron Type 6441

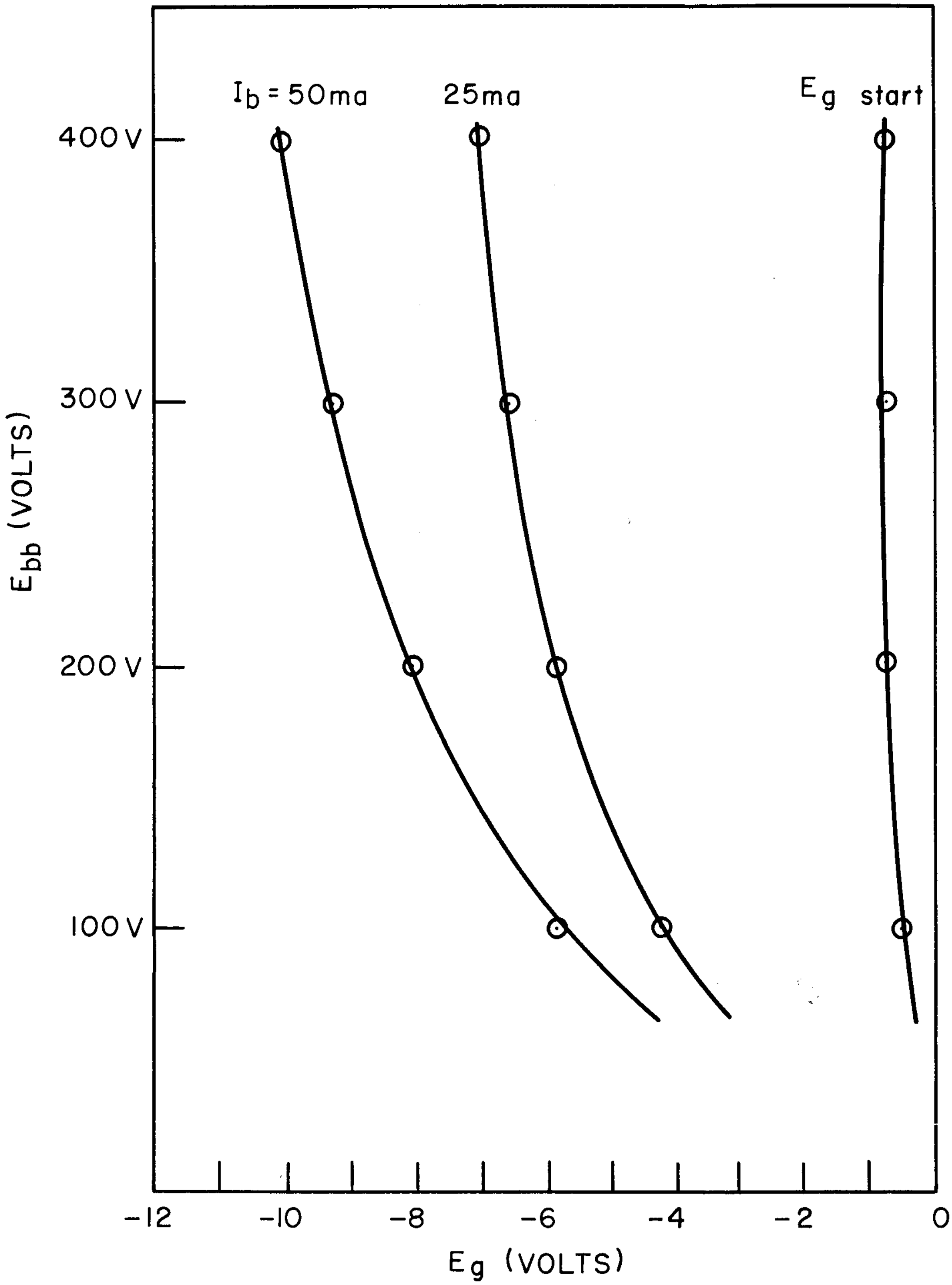


Figure 3 - Firing and Cut-off Characteristics of Tacitron Type 6441

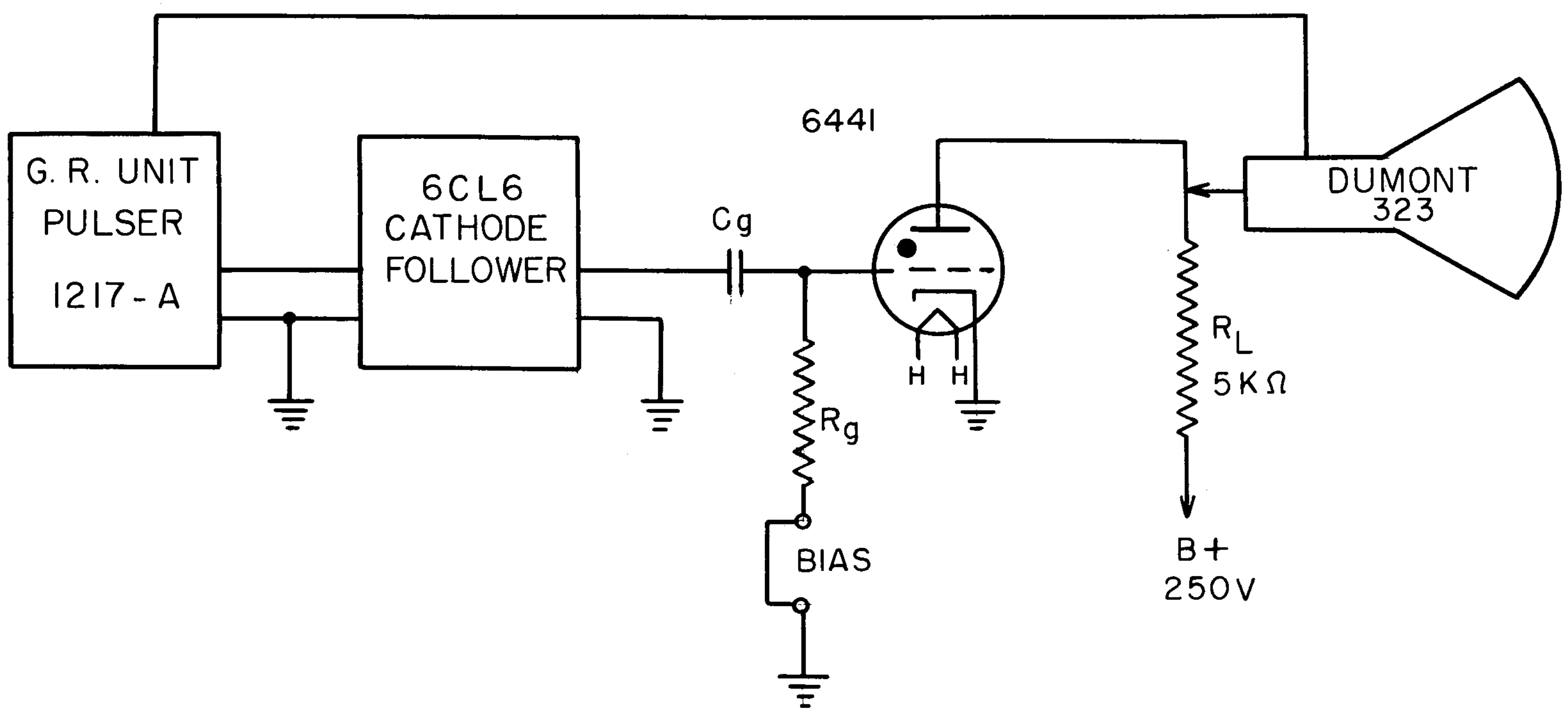
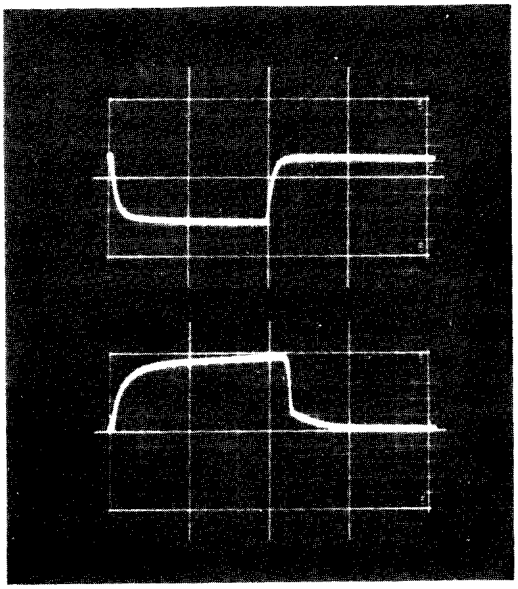


Figure 4 - Experimental Pulse Amplifier using a Tacitron



10-μSEC INPUT PULSE
GRID OF 6441

OUTPUT PULSE
PLATE OF 6441

Figure 5 - Negative Pulse Amplifier Waveforms Illustrating
10 Microsecond Operation

100-μSEC INPUT PULSE
GRID OF 6441

OUTPUT PULSE
PLATE OF 6441

Figure 6 - Negative Pulse Amplifier Waveforms Illustrating
100 Microsecond Operation

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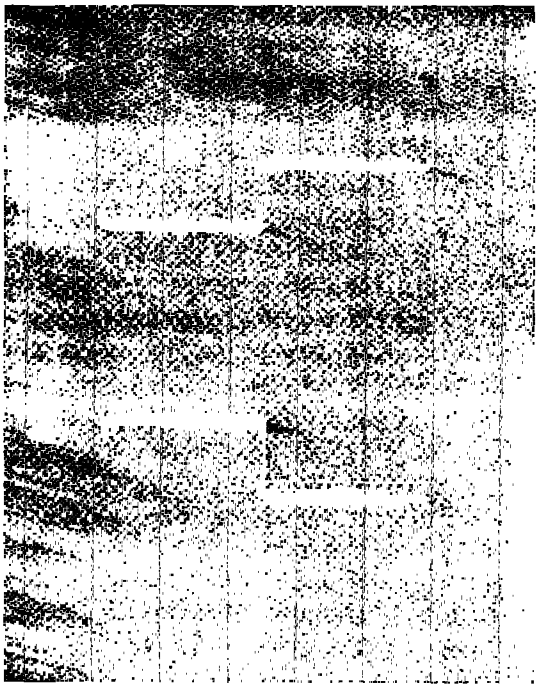
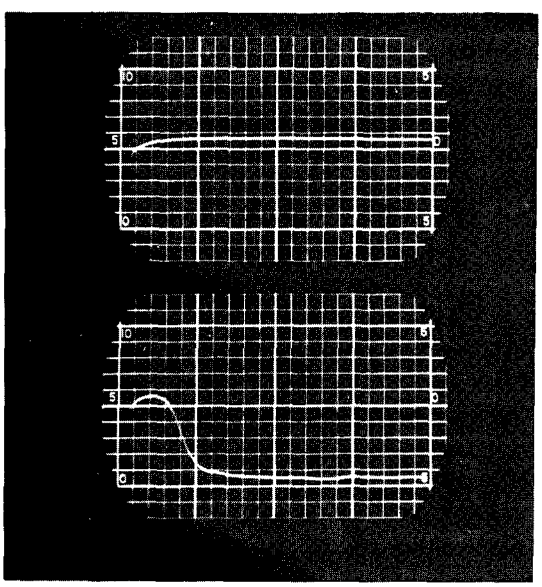


1000-μSEC INPUT PULSE
GRID OF 6441

OUTPUT PULSE
PLATE OF 6441

Figure 7 - Negative Pulse Amplifier Waveforms Illustrating 1000 Microsecond Operation



FIRST 40 MICROSECONDS OF 100 MICROSECOND OUTPUT OF CATHODE FOLLOWER

WAVEFORM ACROSS TACITRON AT SAME SWEEP RATE AS ABOVE

Figure 8 - Operation of the Tacitron with a Pulse Plate Supply Showing Ionization Delay

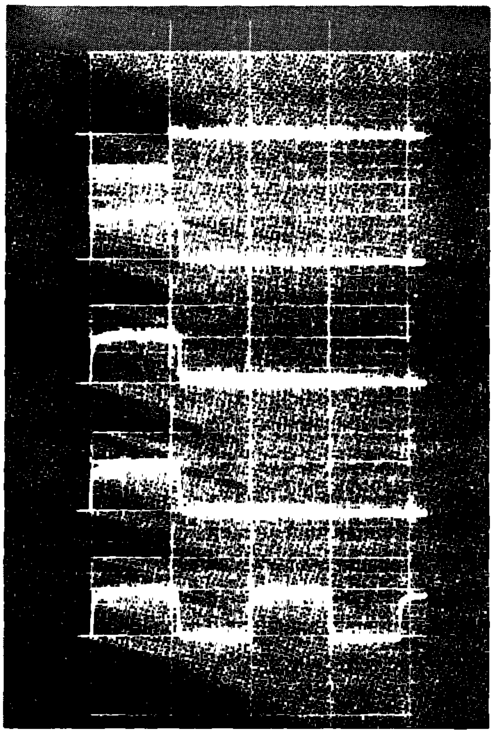


Figure 9 - The Output Waveform of a 100 Microsecond Input Pulse for Various Duty Factors

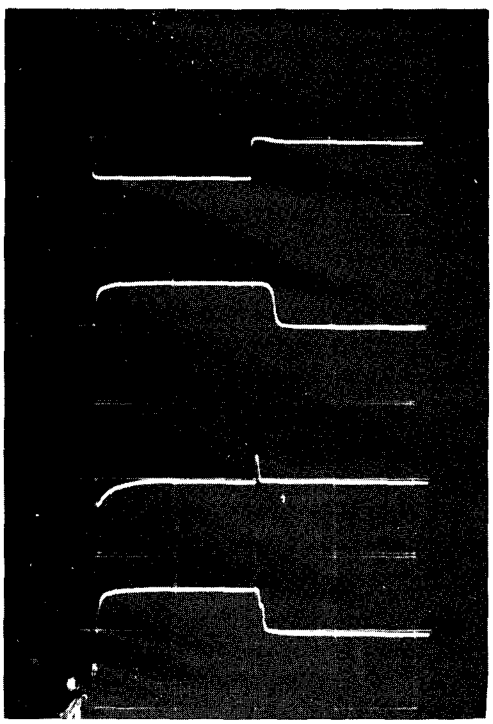


Figure 10 - Output Waveforms with Variation of the Coupling Circuit Time Constant

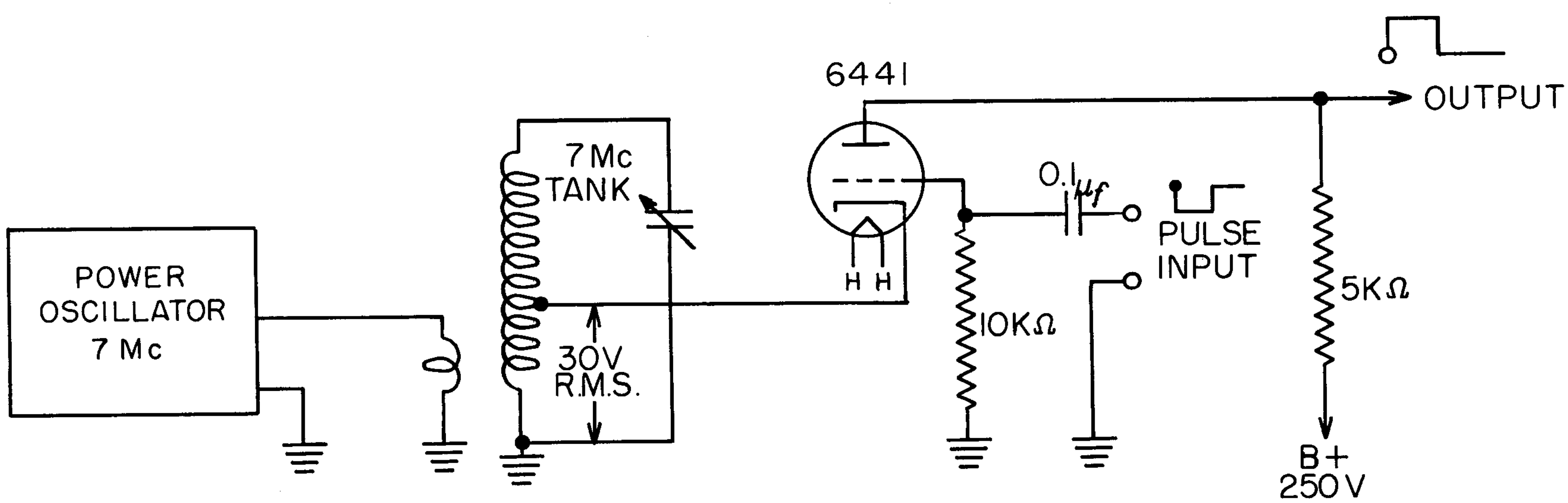


Figure 11 - Circuit for Observing Effect of R.F. "Keep-Alive" Voltage on a Pulse Amplifier

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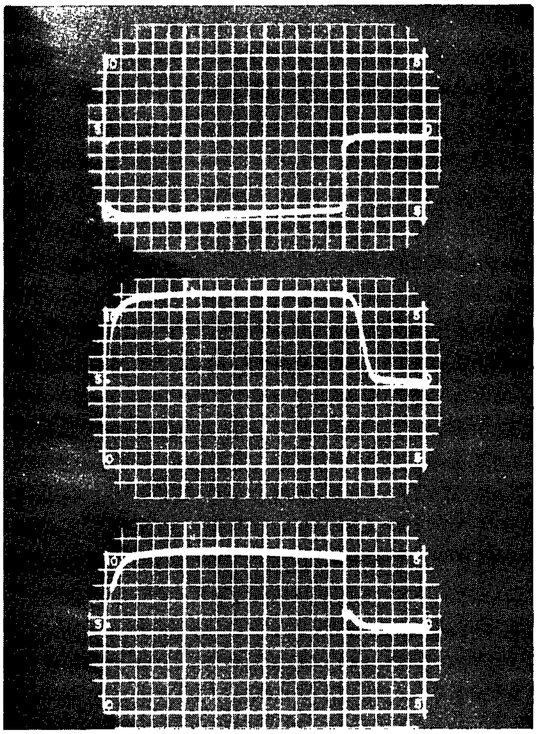
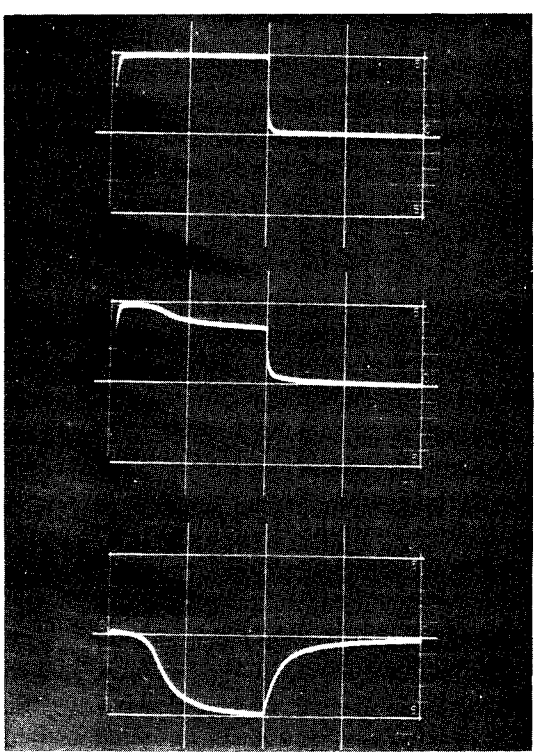


NEGATIVE 100 μSEC PULSE INPUT

POSITIVE PULSE OUTPUT WITHOUT R.F. APPLIED TO THE CATHODE-GRID CIRCUIT

SAME AS ABOVE WITH R.F. APPLIED TO THE CATHODE-GRID CIRCUIT

Figure 12 - Waveforms Showing the Effect of R.F. "Keep-Alive" Voltage in Figure 11

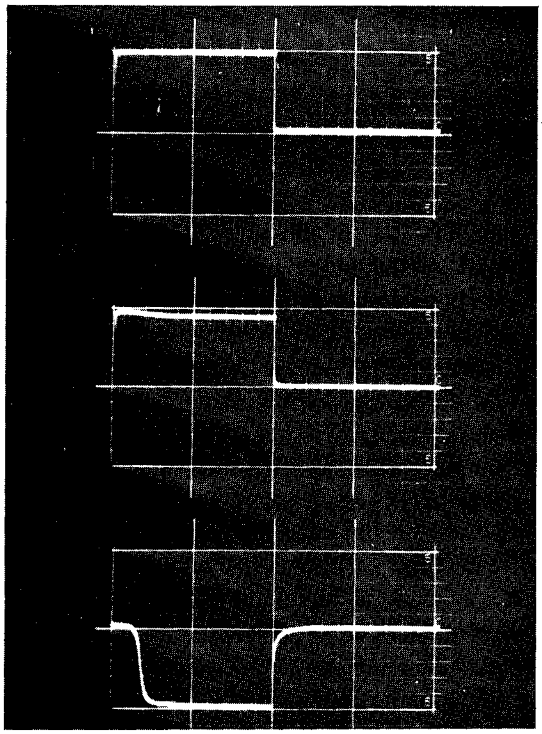


10-μSEC OUTPUT PULSE OF CATHODE FOLLOWER

INPUT PULSE GRID OF 6441

OUTPUT PULSE PLATE OF 6441

Figure 13 - Positive Pulse Amplifier Waveforms with a 10 Microsecond Input Pulse

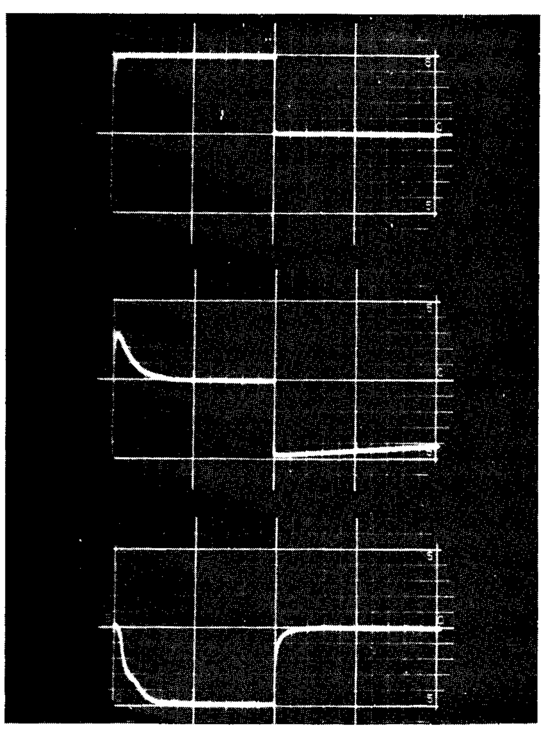


100-μSEC OUTPUT PULSE
OF CATHODE FOLLOWER

INPUT PULSE
GRID OF 6441
C = 8 μf

OUTPUT PULSE
PLATE OF 6441

Figure 14 - Positive Pulse Amplifier Waveforms with a 100 Microsecond Input Pulse and a Coupling Capacitor of 8 Microfarad

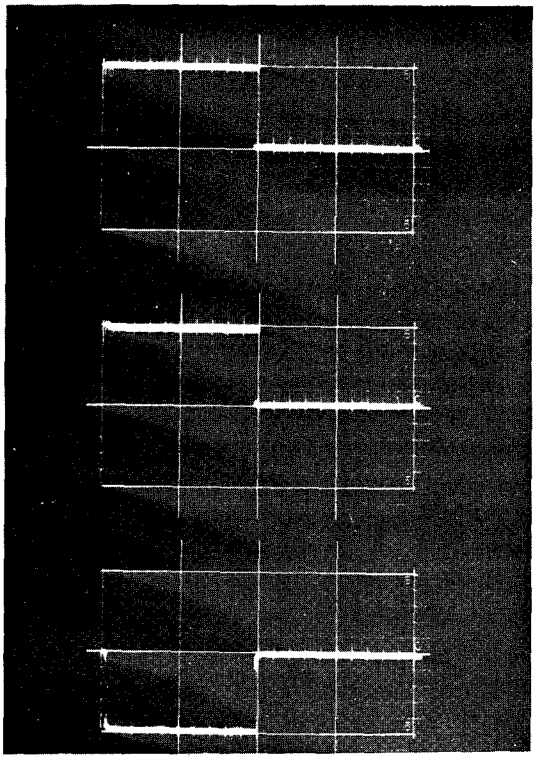


100-μSEC OUTPUT PULSE
OF CATHODE FOLLOWER

INPUT PULSE
GRID OF 6441
C = 0.1 μf

OUTPUT PULSE
PLATE OF 6441

Figure 15 - Waveforms of Figure 14 with Reduced Coupling Capacity

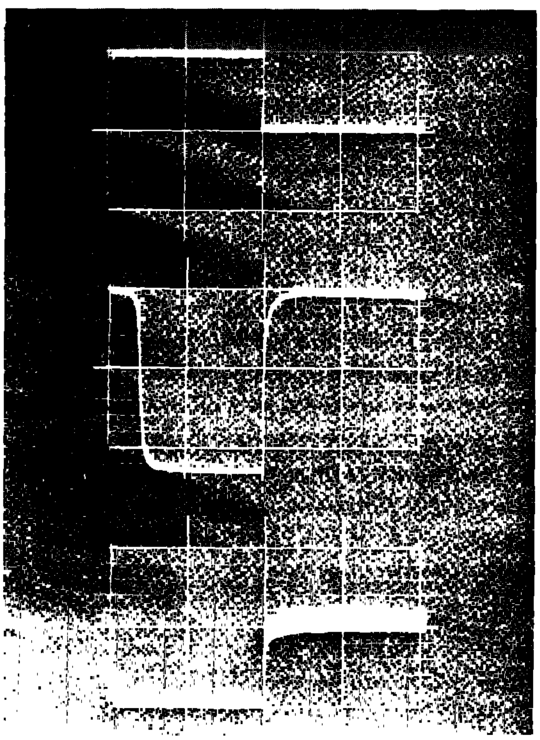


1000 μSEC OUTPUT PULSE
OF CATHODE FOLLOWER

INPUT PULSE AT GRID
OF 6441

OUTPUT PULSE AT PLATE
OF 6441

Figure 16 - Positive Pulse Amplifier Waveforms with a 1000 Microsecond Input Pulse



POSITIVE 100 μSEC PULSE INPUT
TO GRID OF 6441

NORMAL PULSE OUTPUT AT
PLATE OF 6441

PULSE OUTPUT AT PLATE OF 6441
WITH R.F. INJECTED AT THE CATHODE

Figure 17 - Operation of the Positive Pulse Amplifier with R.F. "Keep-Alive" Voltage Applied from Grid to Cathode

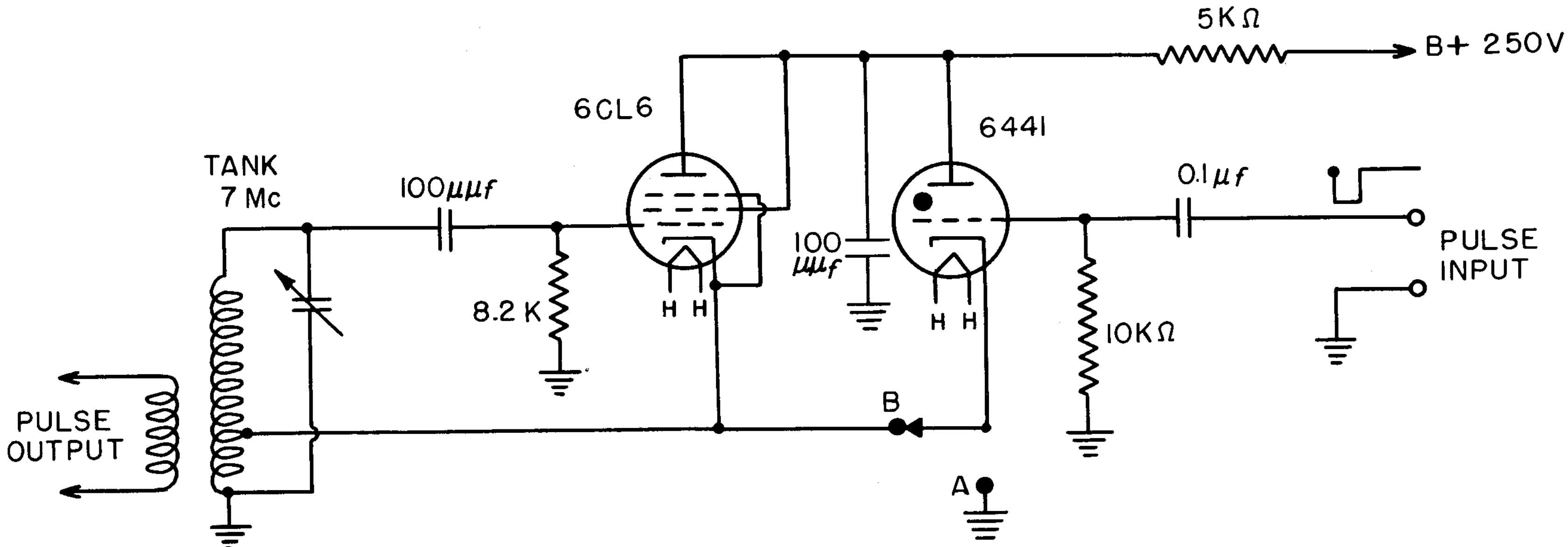


Figure 18 - Circuit Diagram of a Plate Loading Type of Pulse Modulator Using a Tacitron

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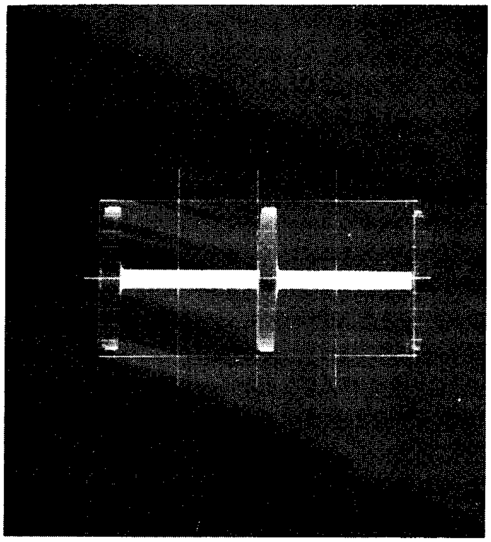
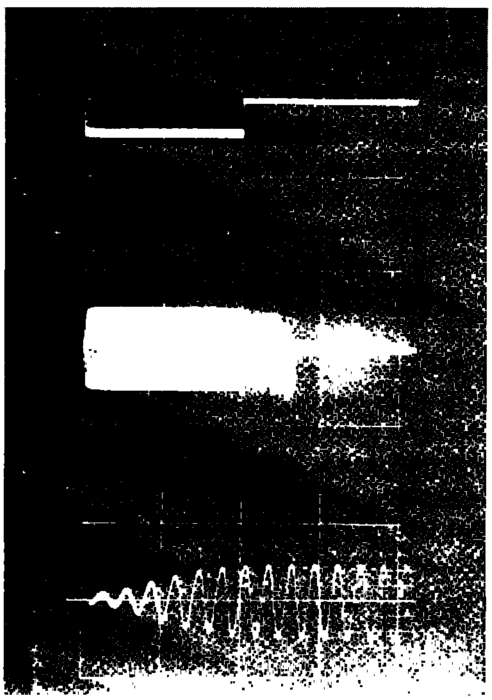


OUTPUT WAVEFORM
CATHODE OF 6441
GROUNDED

Figure 19 - Waveforms for the Circuit in Figure 18 with the Cathode of the 6441 Connected to Position A



100-μSEC INPUT PULSE
SCOPE SWEEP = 200μSEC

OSCILLATOR OUTPUT
SCOPE SWEEP = 200μSEC

OSCILLATOR OUTPUT
SCOPE SWEEP = 20μSEC

Figure 20 - Waveforms of the Pulsed Oscillator in Figure 18 with the 6441 Cathode Switch in Position B

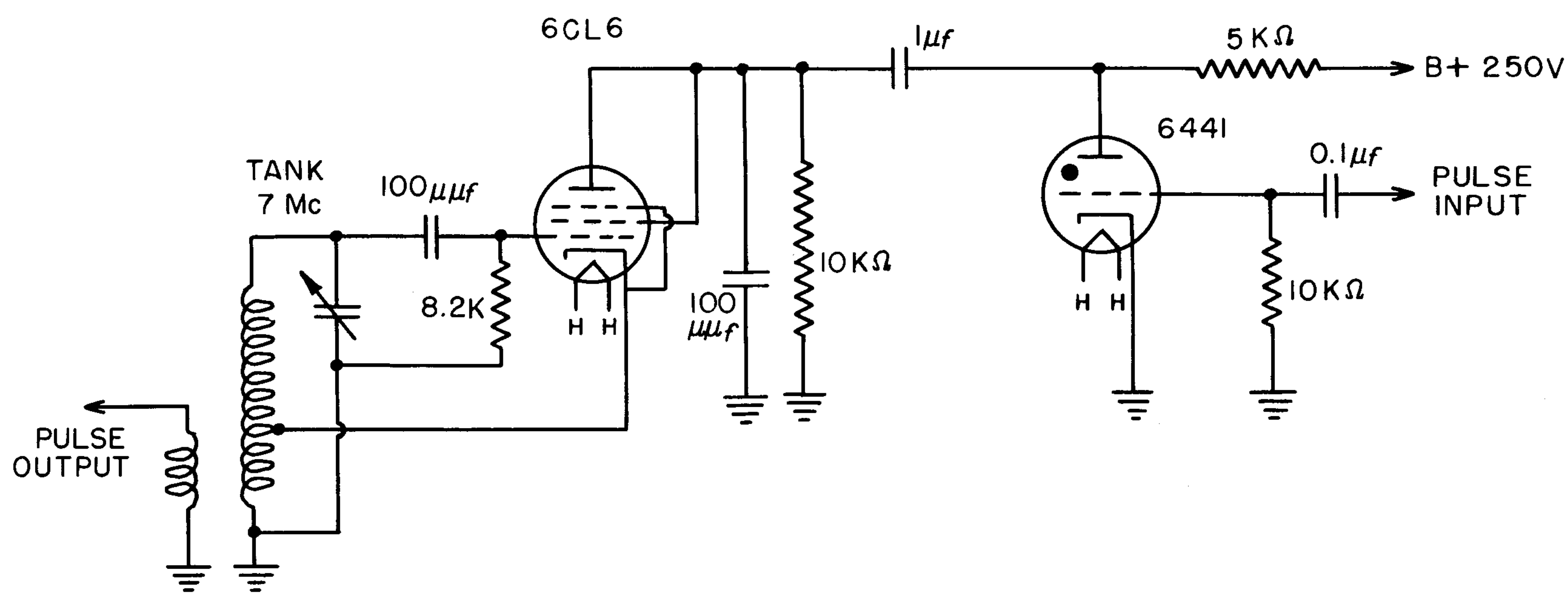


Figure 23 - A Capacity Coupled Pulse Modulator

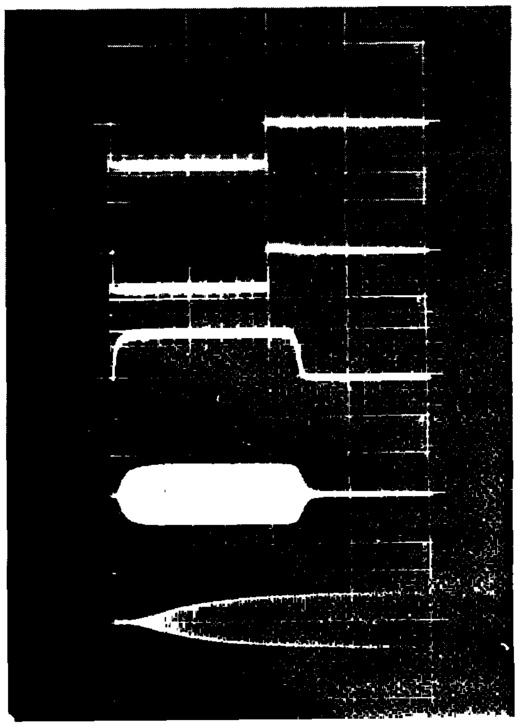


Figure 24 - Waveforms of the Capacity Coupled Pulse Modulator in Figure 23, Illustrating a 100 Microsecond Pulse

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TEXT

FOR

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APPLICATION OF TACITRON RCA TYPE 6441 TO PULSE CIRCUITRY

Richard G. Cumings

June 8, 1956

RADAR TECHNIQUES BRANCH

RADAR DIVISION

NAVAL RESEARCH LABORATORY

WASHINGTON 25, D.C.

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ABSTRACT

The application of a grid controlled gas discharge tube, tacitron, RCA Type 6441, to radar pulse amplifiers and modulators is examined. The tacitron is found useful in some amplifier applications and one method of extending the applications with external excitation is described. As a modulator for a constant starting phase pulsed R.F. oscillator of one type, the tacitron proves to be a useable tube. As a pulse amplifier for pulse widths under 1,000 microseconds with a very low percentage distortion or as a capacity modulator, it has limited applications.

PROBLEM STATUS

This is an interim report on one phase of NRL Problem 53R02-23; work is continuing.

AUTHORIZATION

NRL Problem 53R02-23
Project No. NR 682-230

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INTRODUCTION

The tacitron is a wholly new concept in the field of thyratrons. Ordinary thyratrons, conducting but biased for extinction, continue to conduct until the plate voltage is reduced to zero or passes through zero in the event of cyclic wave supply. The subject tube, however, is fully grid controlled, that is, with positive plate supply it can shut off plate current with an application of a negative bias on the control gird. In addition to having an essentially zero cut-off time, this developmental tube has the added feature of being relatively free of the noise and oscillations commonly observed with conventional hot cathode gas tubes.[1]

Military radar equipments have use for pulsing tubes in various applications and pulse amplifier and pulse modulator circuits using the tacitron were examined. These circuits were evaluated with a practical approach in mind rather than minutely analyzing the theoretical operation of each mode of application. Thus, this application report is not intended to be all inclusive, and though many other uses may well exist, omission of them does not preclude such applications.

GENERAL DESCRIPTION

The tacitron is a thyratron of rather unique construction. The grid, Figure 1, is so made that it forms a shield around both the anode and cathode and separates the two by a wire mesh. Type 6441 has a T-9 bulb and an octal base.

Except for its fully grid controlled, cut-off characteristics the tacitron is analagous to the thyratron. The tacitron configuration, by application of a negative bias to the grid, completely surrounds the positive anode with a field of opposing polarity and inhibits conduction. In addition, the negative grid with the cathode conducts substantially as a gas diode until the tube is deionized. Current is drawn from the source to effect this deionization and it is in the order of 10 to 30 milliamperes depending

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1 Radio Corporation of America, Harrison, N.J., "Preliminary and Tentative Data", June 1954

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on the magnitude of plate current to be extinguished. It is noted from the magnitude of these grid currents that a low impedance driving source is needed to operate the tacitron. In remote relay switching service, the use of a power supply or battery presents no problems. If, however, a tacitron is to be pulse operated, then the driving source should be a cathode follower or other low impedance source.

The tacitron type 6441 is capable of initiating or interrupting a maximum conduction current of 100 milliamperes average with peaks not in excess of 300 milliamperes. The maximum allowable plate voltage is 650 volts. Typical operating values for a 300 volt anode supply are: -15 grid volts required to interrupt a plate current of 100 milliamperes, 30 milliamperes peak grid current, corresponding cut-off time is 0.5 microsecond, and 60 microseconds required for complete deionization.

PULSE AMPLIFIERS

Operating Characteristics

In operating the tacitron in grid control, one applies a negative voltage to the grid of approximately 0-20 volts D.C. It was noted that while one increases grid bias the plate current does not fall to zero instantly, hence a dynamic range of control exists. Measurements of this dynamic range of control were made for two values of plate load resistance and these are shown in Figure 2. It is noted on this figure when the tube has a cathode current of 90 milliamperes, ($R_L = 2.5\ K\Omega$, $E_g = 0$) that the dynamic range exists down to 55 milliamperes at $E_g = -9$ volts, after which the plate current falls off rapidly to zero. Even though the dynamic control range measurements were made rapidly to offset the effect of large grid ion currents, eventually the operation of tacitron, Serial No. 88, was impaired. This was evidenced by a downward shift in control characteristics from approximately -10 volts to -7.4 volts at 300 volts Ebb and 50 milliamperes Ib and an increase in tube drop from 15 to 25 volts. Tacitron tube, Serial No. 189, was used to obtain most of the measurements of this report and tubes, Serial Nos. 185 and 206 were used to determine uniformity of results.

During conduction the tacitron can produce objectional noise if certain precautions are not taken. The quantity however, is claimed to be considerably less than that produced by a thyratron as long as the peak noiseless current, recommended by the manufacturer, is not exceeded. In the case of the Type 6441 tacitron, this value is 300 millamperes peak with maximum average current 100 milliamperes.

An estimate of the noise source capabilities was made by capacity coupling a tacitron with a 100 millamperes average conduction to the antenna terminals of a Collins 51J receiver and a Navy RBA receiver. It was found that the noise spectrum existed at about 30 microvolts level rather uniformly from 20 kc to 10 mc, then fell gradually to almost undiscernible magnitude at 30 mc. Two tacitrons, however, showed remarkably high output at 68 kc and 85 kc respectively with harmonic areas of these frequencies readily detectable above the background.

The cut-off and starting characteristics were determined for various values of plate voltage and these are shown in Figure 3 for two values of plate current. The shape of the curves and magnitude of typical values agree substantially with that published by the manufacturer.

Negative Pulse Amplifier

The essential circuit features for this evaluation are shown in Figure 4. A General Radio Unit Pulser was used to generate a pulse of variable width and repetition rate. The load resistance, R_L, was chosen to give a plate current of 50 milliamperes at approximately 250 volts. C_g and R_g were chosen so as not to degrade the pulse widths under test. The oscilloscope, a Dumont 323, has a calibrated sweep and vertical input. The sweep accuracy is 5 percent of a major scale division or 1.25 percent of the total sweep, and the vertical calibration accuracy is 5 percent overall.

The application of a negative pulse to the grid of the tacitron produced varying results dependent on the pulse width. The pulse output with a 10 microsecond input pulse had output pulse length distortion as shown in Figure 5. The trailing edge of the trigger pulse is noted to be down to 25 percent of maximum in 0.5 microseconds, whereas the output pulse was lengthened by 1.5 microseconds in the time it takes to fall to 25 percent of maximum. Actually the trailing edge did not even begin to fall until 1 microsecond from the same point on the input waveform so the total distortion was 1 microsecond.

A 100 microsecond pulse observed under optimum conditions also showed output pulse length distortion as shown by Figure 6. The fall time of the 100 microsecond trigger was observed to be less than 1 microsecond. The corresponding output pulse fall time was 5 microseconds and had an additional length distortion of 10 microseconds.

Figure 7 shows the pulse length distortion of a 1,000 microsecond pulse. It was not easily discernible, however, the lengthening of the trailing edge was estimated to be approximately the same as that observed for the 100 microsecond pulse. These observations make the pulse length distortion only 1 percent for a 1,000 microsecond pulse whereas this figure is 15 percent for a 100 microsecond pulse and 10 percent for a ten microsecond pulse. The leading edge of the output pulse seems to be unaltered for all pulse lengths and corresponds to that of the input pulse.

Examination of the delay in the occurrence of the trailing edge of the output pulse showed the ionization time of the tube to be the critical factor. A 250 volt positive pulse from a very low impedance source was applied to the tacitron with the grid and cathode common. Under these conditions observation of the plate waveform, Figure 8, shows the equivalent tacitron diode takes approximately 15 μ seconds before full conduction is achieved. This value is the same order of magnitude as the length distortion for pulses in excess of 100 microseconds as discussed previously. The total deionization time for the tacitron is specified as 60 microseconds. Hence, for pulse lengths under 60 microseconds the time for complete reionization should be less. This factor accounts for the smaller length distortion observed in the 10 microsecond case, Figure 5.

The output impedance of the amplifier as a voltage source, Figure 4, was found to be essentially equal to current limiting resister R_L. The output voltage (no load) was found to be close to the power supply voltage with the tube drop constant at 15 volts over a large range of plate currents. As the tacitron is essentially an on or off device, the output voltage remained independent of pulse width and pulse repetition rate and of input pulse amplitude as long as it exceeded the current cut-off value, Figure 3.

The duty factor of the pulse does not affect the output wave shape over considerable range. Figure 9 shows the 100 microsecond input pulse and four duty factors of 1/20, 1/10, 1/5 and 1/2 respectively.

A small variation in the coupling circuit time constant, consisting of C_g and R_g, had no appreciable effect. However, if this time constant is reduced sufficiently to allow differentiation, the output pulse reduces its length to nearly that of the input pulse. Under the letter conditions, distortion in the form of a small step on the trailing edge is noted. Figure 10 illustrates input and output waveforms, one with normal and one with reduced time constant.

In subsequent experiments involving pulsed oscillators it was discovered that radio frequency had a "keep alive" effect on the ionization time. To check the effect of a "keep alive" R.F. voltage on the negative pulse amplifier, the circuit of Figure 11 was used. R.F. energy was fed to a tuned circuit and the cathode of the tacitron connected to a tap on the coil. A 100 microsecond negative input pulse produced the waveforms seen in Figure 12. The pulse output with the "keep alive" R.F. voltage has very little width distortion as compared to the conventional operation.

Positive Pulse Amplifier

A positive pulse amplifier circuit was examined, one similar to the negative version, Figure 4. A fixed negative grid bias was applied but was found not to be essential if grid current and R_g developed the proper operation bias. The input consisted of a positive pulse derived from a General Fadio Unit Pulser coupled capacitively through a cathode follower to the grid of the tacitron.

A 10 microsecond input pulse produced an output pulse severely distorted in shape and length. As shown by Figure 13, the output waveform, taken at the plate of the tacitron, rises negatively for the entire pulse length, never quite reaching the maximum pulse amplitude. The trailing edge falls off exponentially for 5 microseconds.

A 100 microsecond input pulse produced an output pulse significantly distorted only at the leading edge, as illustrated by Figure 14. This distortion appears to be of the same order of magnitude as the ionization time, approximately 20 microseconds. Of hote with this type of operation, the effect of the grid input circuit is very pronounced.

A low impedance cathode follower was requisite and the coupling capacitor was in the order of 8 microfarads. Use of a coupling capacitor of 0.1 microfarad resulted in the distorted effect on the input pulse in Figure 15.

As in the 100 microsecond pulse operation the 1,000 microsecond input pulse produced little distortion other than that of the leading edge, equivalent to the ionization time approximately. Figure 16 illustrates the 1,000 microsecond pulse operation.

Radio frequency "keep alive" voltage introduced in the grid - cathode circuit reduced the ionization time as in the negative pulse amplifier. Figure 17 shows the normal operation without "keep alive" voltage and operation with "keep alive" voltage added to the grid - cathode circuit in the same manner as shown in Figure 11. The leading edge has very little distortion, however, unwanted R.F. appears in the output. It is possible that with the addition of a "keep alive" electrode to the tube, the aforementioned objection would be overcome if direct potential would suffice.

PULSE MODULATORS

Plate Loading Modulator

The ability of the tacitron to pass considerable plate current lends itself readily to circuits involving the control of continuous oscillations. The tacitron has a plate resistance of 300 ohms at 50 milliamperes plate current and a filament dissipation of 3.78 watts. A comparable low impedance vacuum tube such as the 6AS7-G requires much more mounting space and has a filament dissipation of 15.75 watts. In addition, to completely interrupt a current of 50 milliamperes the 6AS7-G requires a pulse input of 150 volts as compared to approximately 9 volts for the tacitron, Type 6441. The tube was used in a plate loading modulator circuit, as shown in Figure 18, with a nominal R.F. frequency of 7 megacycles and repetition rate of 500 cycles per second. In the first trial of this circuit the cathode of the 6441 was grounded with the result shown in Figure 19, where it is noted that the low voltage drop across the tube was not enough to completely dampen oscillations between pulses.

Connection of the cathode to the cathode tap of the oscillator or a turn or two higher, Figure 18, results in the waveform, Figure 20. The output waveform obtained is excellent with rise and fall positions agreeing with that of the input pulse. Rise time of the input 100 microsecond pulse was 0.5 microseconds and that of the output pulse 1 microsecond. The tacitron, Figure 18, is connected on the lower section of the tank coil, hence, it has only small effect on the frequency of the R.F. In addition, the plate current from the tacitron is in the proper direction to promote fast build up and decay of oscillations, hence, better starting phase is insured. Excellent coherence and phase stability were noted. Examination of successive pulses by a multiple exposure camera picture revealed no erratic starting phase. In addition, the output pulse appeared to have constant R.F. phase at the trailing edge also. Figure 21 shows the expansion of this trailing edge. Examination of other pulse widths and rise times showed comparable operation. The rise time of the output pulse remained approximately 1 microsecond regardless of pulse width. When the rise time at the grid exceeded 1 microsecond, the output pulse follows the shape of the modulating pulse.

The modulator waveform shows very little trailing edge distortion of the output pulse as compared to the negative pulse amplifier. Radio frequency existing between cathode and grid of the tacitron apparently prevents complete deionization. If an R.F. choke is inserted in the cathode lead of the tacitron then the trailing edge distortion is present in the modulator as seen by Figure 22.

Plate Coupled Modulator

A 7 Mc Hartley oscillator was connected such that its plate voltage was a pulse capacitively coupled from the 6441 as shown by Figure 23. In this arrangement the input pulse used was 100 microseconds long at 500 cycles repetition rate. The corresponding output pulse was distorted by extended pulse length and slow rise and fall times as was the case in the pulse amplifier. Figure 24 shows the modulation input, the grid waveform, plate waveform and two views of the output pulse, the lower being at 1/10 the sweep time of the upper trace. As can be seen from Figure 24, this type of operation is not recommended when exact synchronization and precise pulse length are desired. Also, the starting phase was not constant due to the rather slow build up of oscillations. Other variations of this circuit such as introducing the pulse in the grid and cathode circuits were tried but with the same results as in Figure 24.

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CONCLUSIONS

In conculsion, it is found that negative pulse input operation of the tacitron introduces distortion of the output pulse in the form of trailing edge lengthening of 15 to 20 microseconds. For operation with a small percentage distortion, pulse widths over 1,000 microseconds could be amplified. Where the leading edge is the principal consideration and the rise time of the input pulse is greater than 0.5 microsecond the tacitron is useable for this operation. Injection of a "keep alive" voltage either in the circuitry or possibly through modification of the tube by inserting a special electrode is indicated as a method of overcoming the ionization delay and reducing the accompanying pulse width distortion.

Positive pulse input operation distorted the leading edge of the output pulse by the amount of the ionization time. For operation in which a leading edge delay is not important the tacitron could be used. At pulse widths above 1,000 microseconds, the percentage distortion is found to be small. "Keep alive" voltage injection is found to be effective in reducing distortion to a negligible degree.

The tacitron is found to be useful in a modulator of the plate loading type. Godd pulse shape, constant starting phase and coherence throughout the R.F. pulse are noted. Operation with small pulse widths is limited by the .5 microsecond minimum cut-off time. As a plate coupled modulator, the tacitron has limited applications.

ACKNOWLEDGEMENTS

The contribution of several developmental tacitrons by the Radio Corporation of America is gratefully acknowledged. The preliminary and tentative data supplied by the same company was appreciated.

TITLES OF FIGURES

1. Element Arrangement of a Tacitron and a Thyratron.

2. Dynamic Characteristic of Tacitron Type 6441.

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4. Experimental Pulse Amplifier Using a Tacitron.

5. Negative Pulse Amplifier Waveforms Illustrating 10 Microsecond Operation.

6. Negative Pulse Amplifier Waveforms Illustrating 100 Microsecond Operation.

7. Negative Pulse Amplifier Waveforms Illustrating 1,000 Microsecond Operation.

8. Operation of the Tacitron with a Pulse Plate Supply Showing Ionization Delay.

9. The Output Waveform of a 100 Microsecond Input Pulse for Various Duty Factors.

10. Output Waveforms with Variation of the Coupling Circuit Time Constant.

11. Circuit for Observing Effect of R.F. "Keep-Alive" Voltage on a Pulse Amplifier.

12. Waveforms Showing the Effect of R.F. "Keep-Alive" Voltage in Figure 11.

13. Positive Pulse Amplifier Waveforms with a 10 Microsecond Input Pulse.

14. Positive Pulse Amplifier Waveforms with a 100 Microsecond Input Pulse and a Coupling Capacitor of 8 Microfarad.

15. Waveforms of Figure 14 with Reduced Coupling Capacity.

16. Positive Pulse Amplifier Waveforms with a 1,000 Microsecond Input Pulse.

17. Operation of the Positive Pulse Amplifier with R.F. "Keep-Alive" Voltage Applied from Grid to Cathode.

18. Circuit Diagram of a Plate Loading Type of Pulse Modulator Using a Tacitron.

19. Waveforms for the Circuit in Figure 18 with the Cathode of the 6441 Connected to Position A.

20. Waveforms of the Pulsed Oscillator in Figure 18 with the 6441 Cathode Switch in Position B.

21. Trailing Edge Expansion of the Output Waveform of Figure 20.

22. Waveforms Showing the Effect of Introducing a R.F. Choke in the Cathode Lead of the 6441 of Figure 18.

23. A Capacity Coupled Pulse Modulator.

24. Waveforms of the Capacity Coupled Pulse Modulator in Figure 23, Illustrating a 100 Microsecond Pulse.

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